An Onboard Data Analysis Method to Track the Seasonal Polar Caps on Mars

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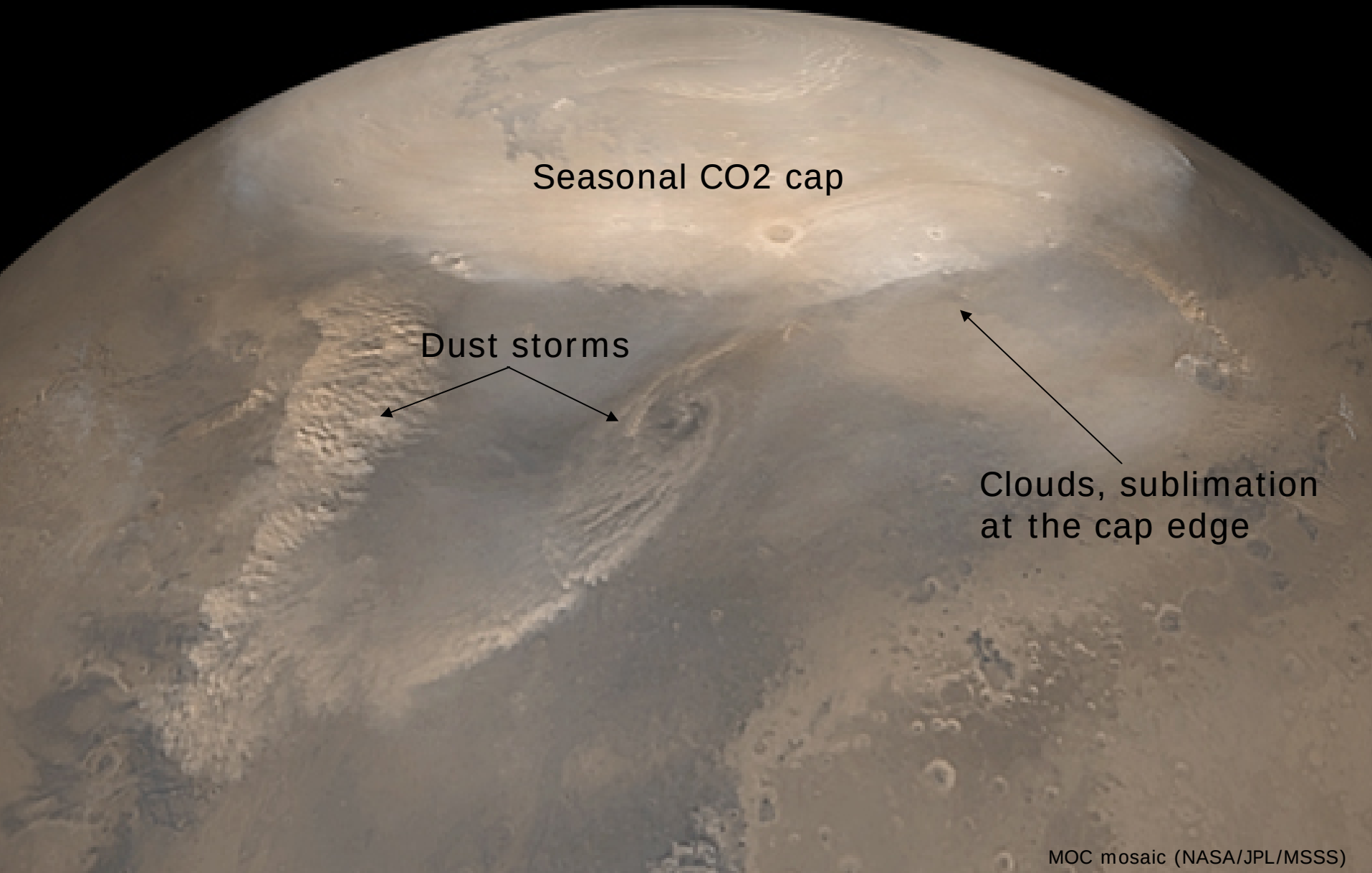
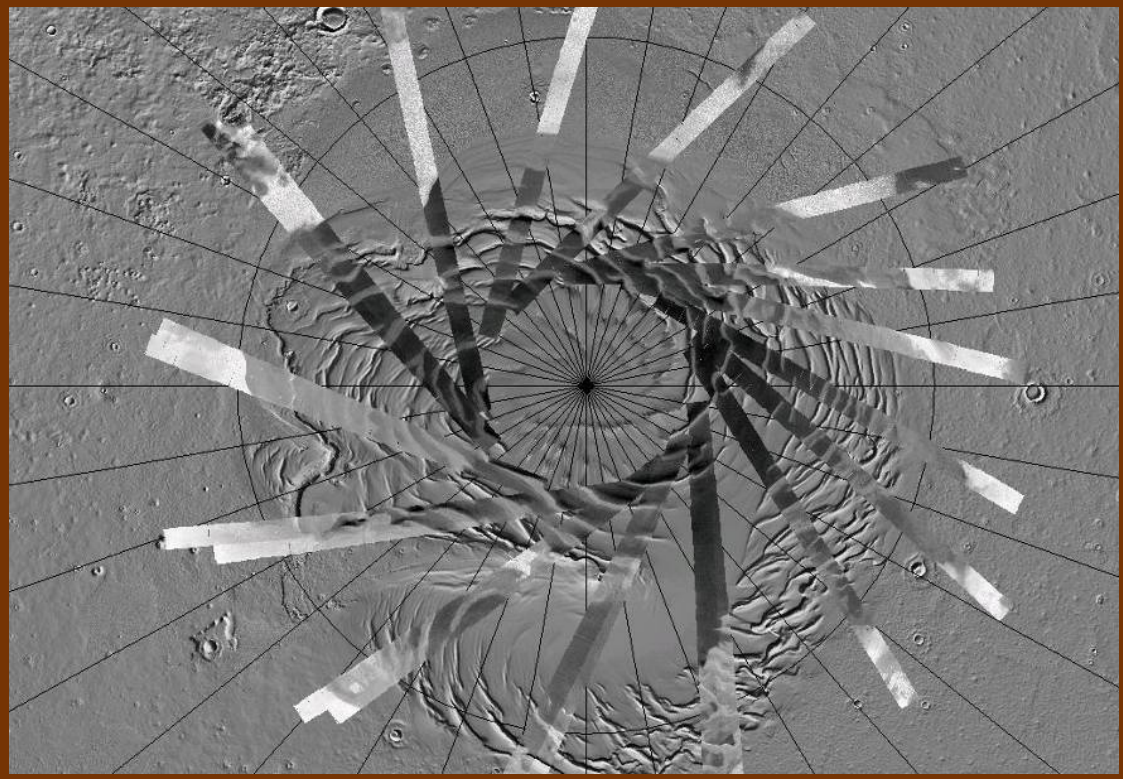
Recession of the seasonal CO2 cap, northern spring



MOC mosaic (NASA/JPL/MSSS)

Mars Seasonal Polar Cap Tracking using THEMIS IR Data

Typical THEMIS coverage of the pole:



Mars, North Pole, THEMIS orbits 4319-4399 (northern summer)
JMARS visualization - Noel Gorelick, ASU

THEMIS on MGS

Relevance to Onboard Science

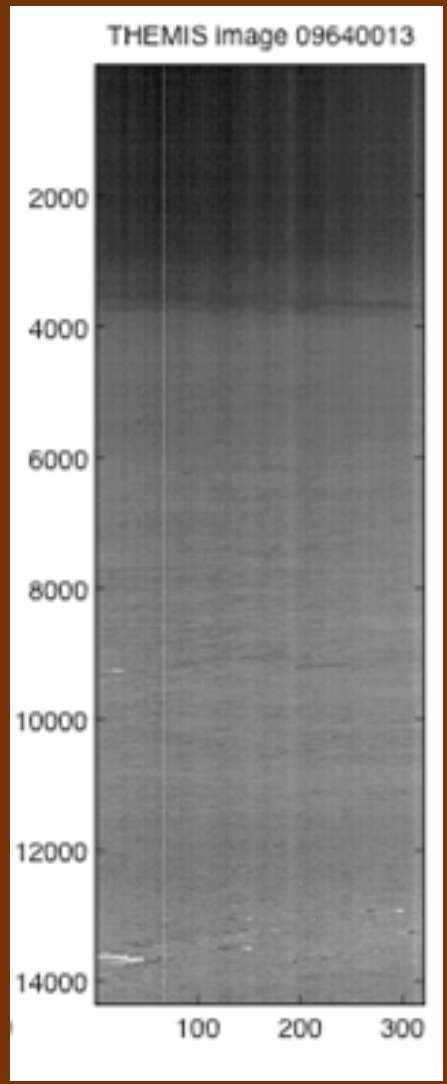
- General goals
  - Increase spatial and temporal coverage of specific features of interest
  - Adhere to existing bandwidth constraints
- Polar cap tracking on Mars
  - THEMIS orbits 12 times per sol, but targets the polar cap only a fraction of the time
  - Each targeted image consumes a large chunk of bandwidth
- General approach
  - Increase coverage by analyzing data onboard instead
  - Prioritize data for transmission based on the presence of features of interest (e.g., cap edge)
  - No change to bandwidth required; increase in active computing time required

Bimodal Image Temperature (BIT) Histogram Analysis

- Basic Assumption
  - Images with the cap edge will have both cold (ice or frost) and warm (non-ice) pixels
- Approach
  - Dynamically identify temperature threshold T between the two groups to separate ice and non-ice
    - T is defined as the low point between two peaks in the histogram of pixel temperatures
    - Independent of calibration (can use raw EDRs)
  - Mark ice/non-ice pixels in image using threshold T
  - Define “cap edge” as the first image row with < 50% ice

Example

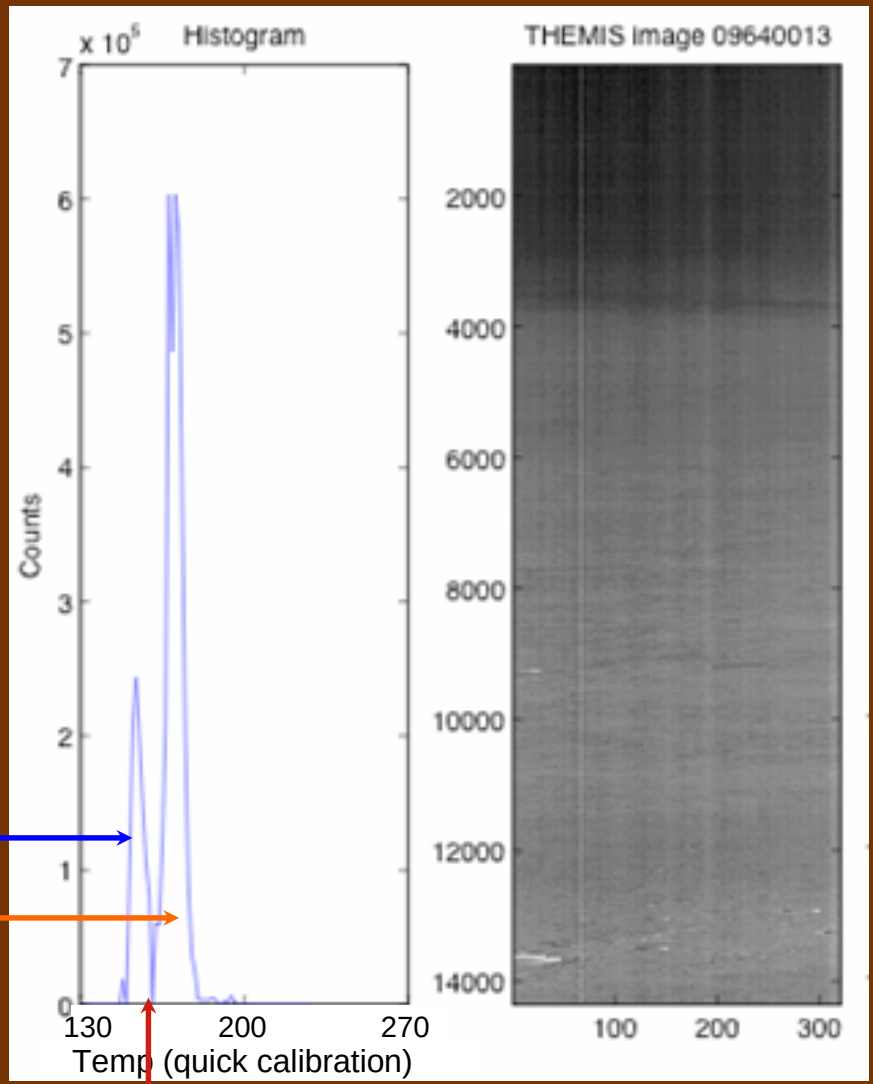
EDR



L_s = 351

Example

EDR



CO2 Ice

Non-ice

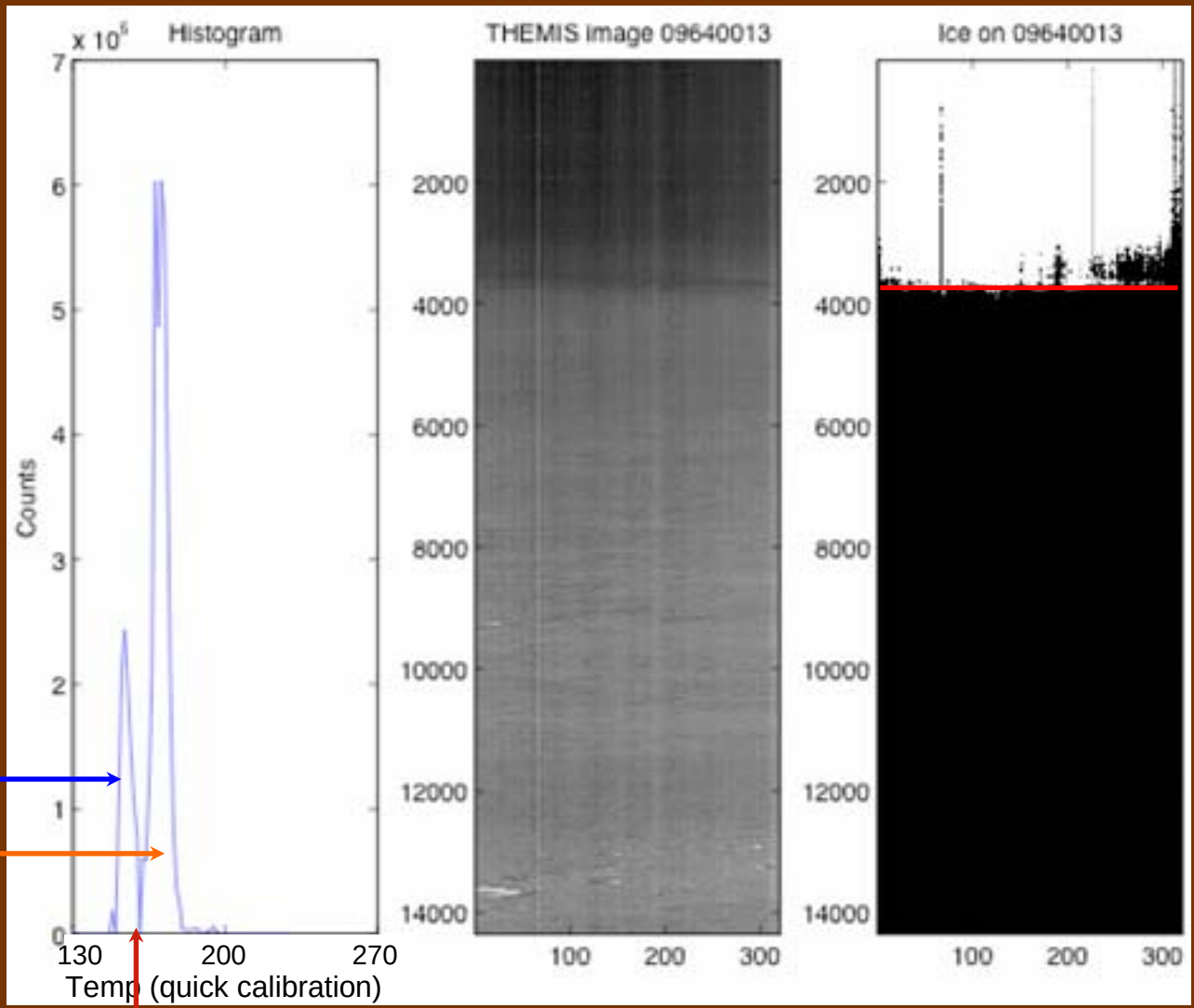
Computed threshold = 172 K

L_s = 351

Example

EDR

Classification



Cap edge
Latitude = 59.6

CO2 Ice

Non-ice

Computed threshold = 172 K

L_s = 351

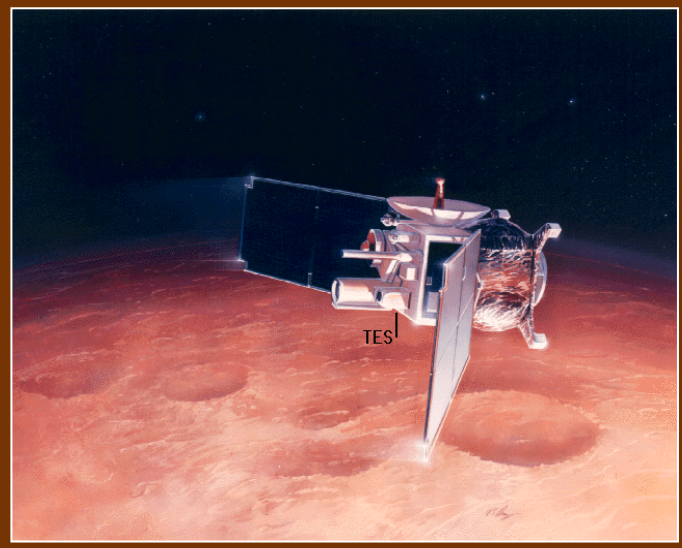
How well does it work?

- Evaluated against two standards
  1. Model derived from contemporary TES observations
  2. Manual annotations of THEMIS data

- Evaluated in two ways
  1. Agreement on whether an image contains the cap edge at all
  2. Deviation in position of identified cap edge

BIT Validation: TES Year 3 Model

- Model based on Thermal Emission Spectrometer (TES) data
  - TES data binned into 60-km cells
  - Look for where temperature exceeds 165 degrees (crocus date)
  - 51-coefficient best fit model of sines and cosines



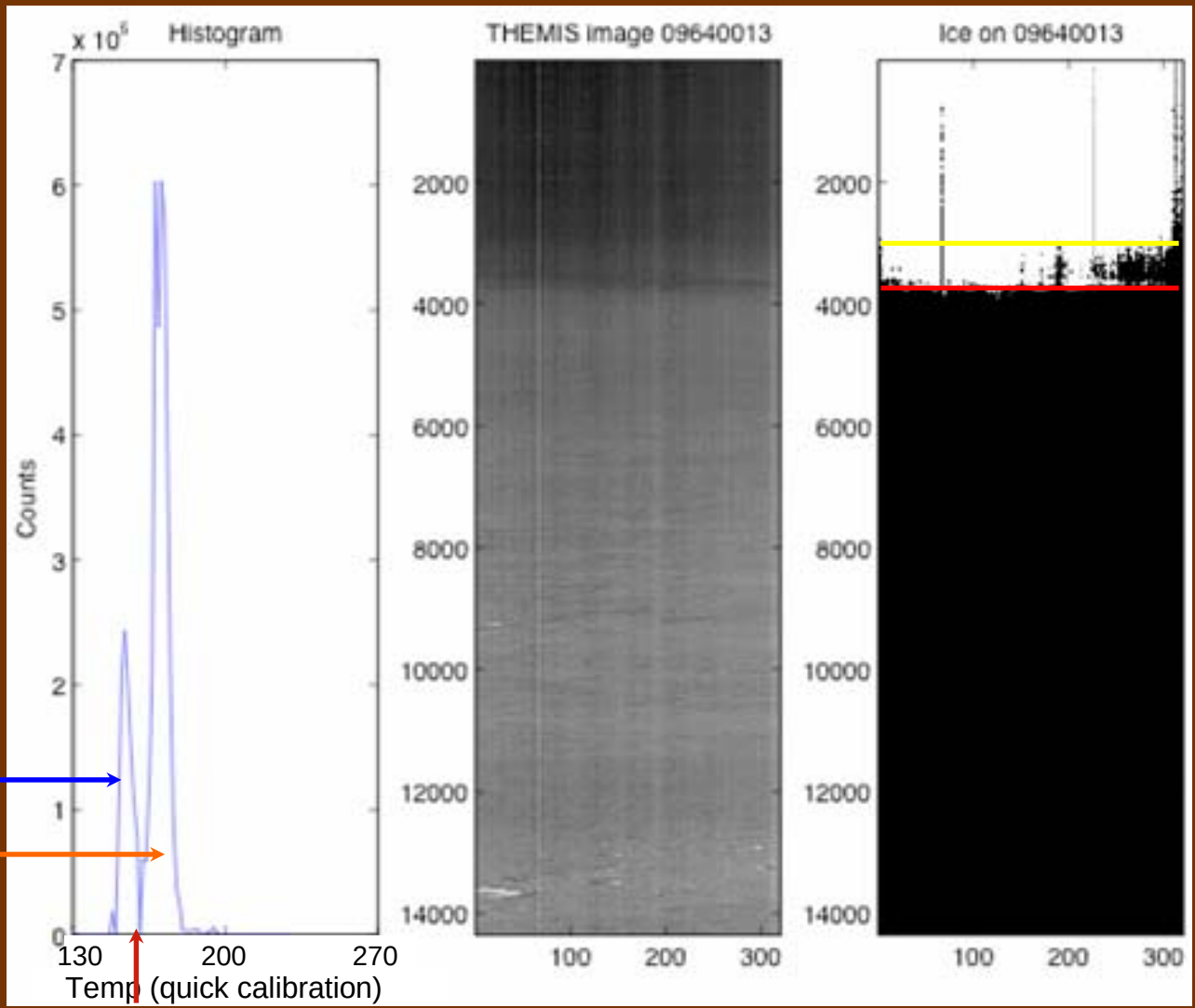
TES on Mars Global Surveyor

- Separate models for each TES year
  - Error estimate (each model): 1.2-1.4 degrees (72-84 km)
  - Observed interannual deviations ~3 degrees (180 km)

Example

EDR

Classification



TES model:
60.9 +/- 1.4

Cap edge
Latitude = 59.6

CO_2 Ice

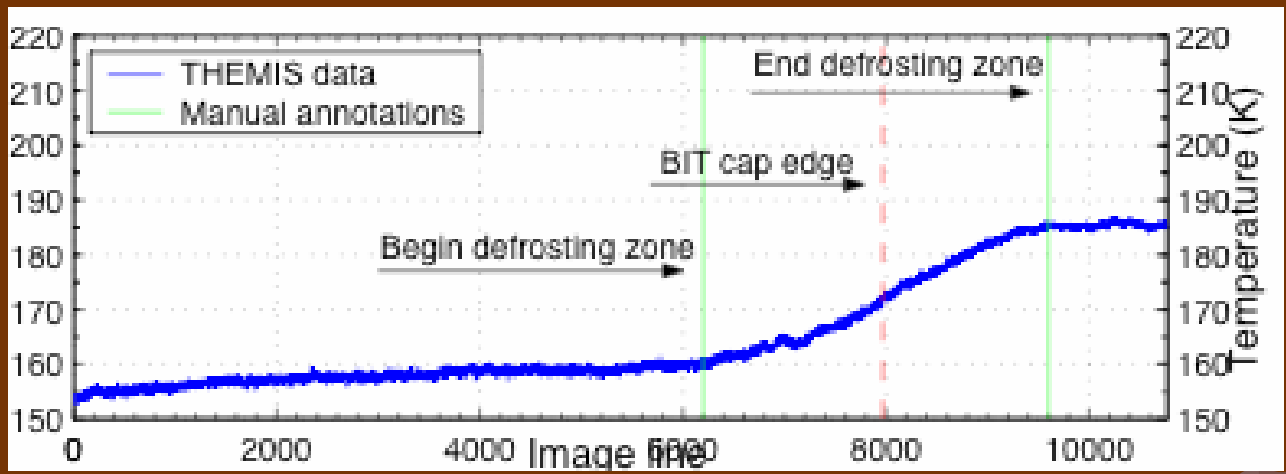
Non-ice

Computed threshold = 172 K

L_s = 351

BIT Validation: Manual Annotations

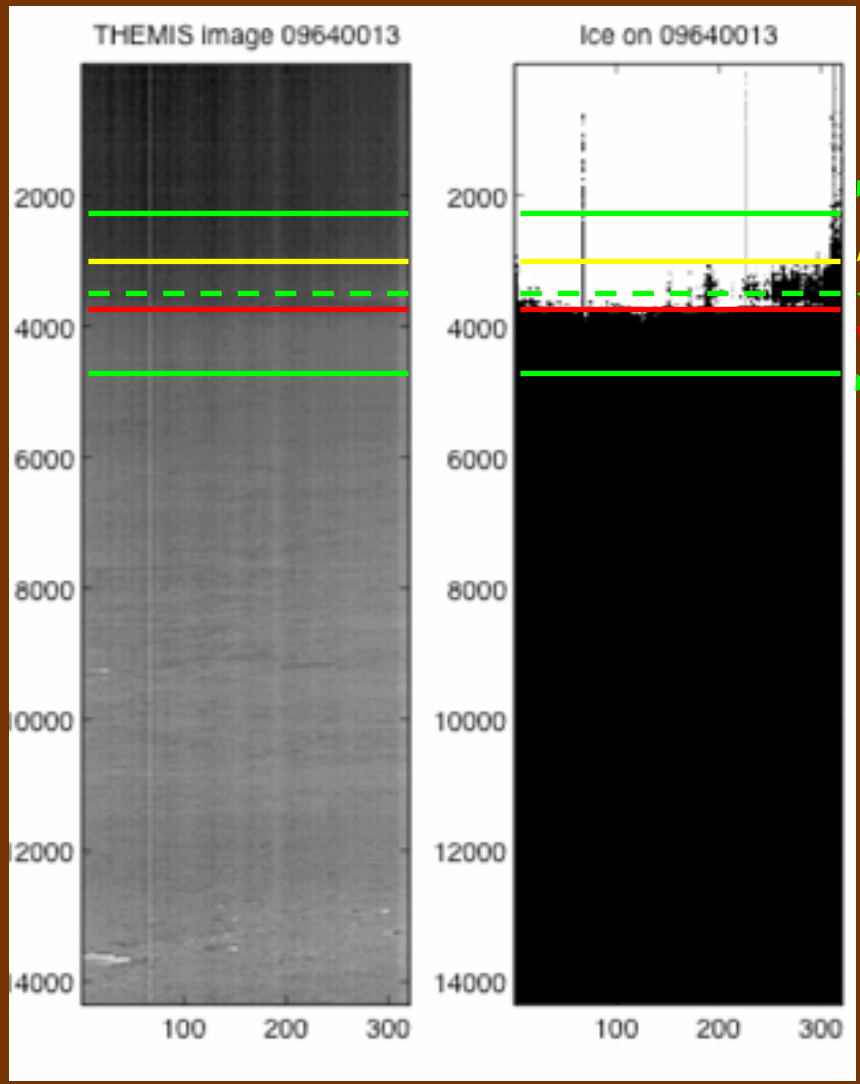
- Manually labeled 435 THEMIS images
  - Based on thermal profile, not histogram
    - Profile of mean row temperature values
- Technique
  - Annotated the beginning and end of the CO_2 defrosting zone, to the nearest 100 lines (10 km)
  - Computed the cap “edge” as the midpoint between the beginning and end



Example profile with ‘begin’ and ‘end’ annotations

Example

EDR Classification



Manual: begin defrost zone

TES Year 3 Model

Manual cap edge

BIT

Manual: end defrost zone

Key:

- BIT
- TES model
- Manual

BIT Polar Cap Detection Accuracy

- Compare agreement on presence of cap edge in images
- Manual annotations compared to the TES model:
  - Agreement on 426/435 (98%) of images about presence of polar cap edge

Agreement on Presence of Cap Edge in Image

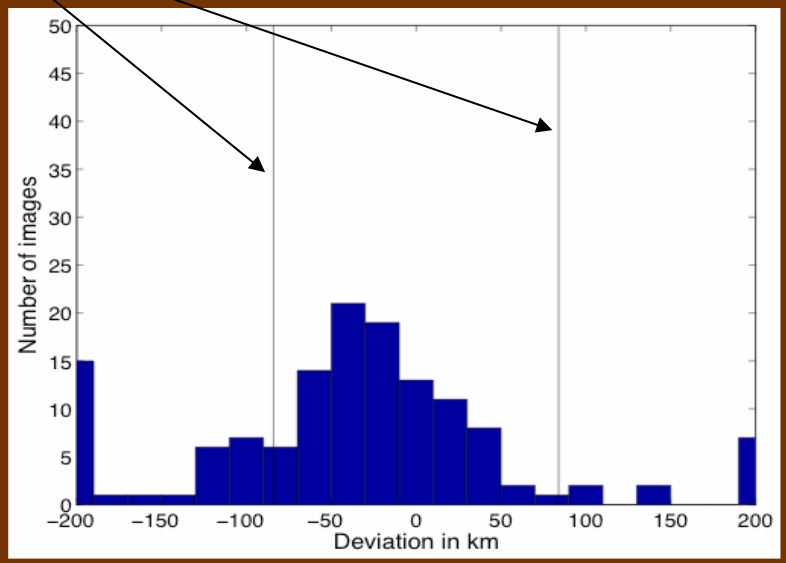
	TES model agrees with BIT	TES model disagrees with BIT	Manual annotations agree with BIT	Manual annotations disagree BIT
BIT Detection	137	4	133	8
No BIT detection	282	12	273	21
Total	419/435 (96%)	16	406/435 (93%)	29

Polar Cap Edge Precision

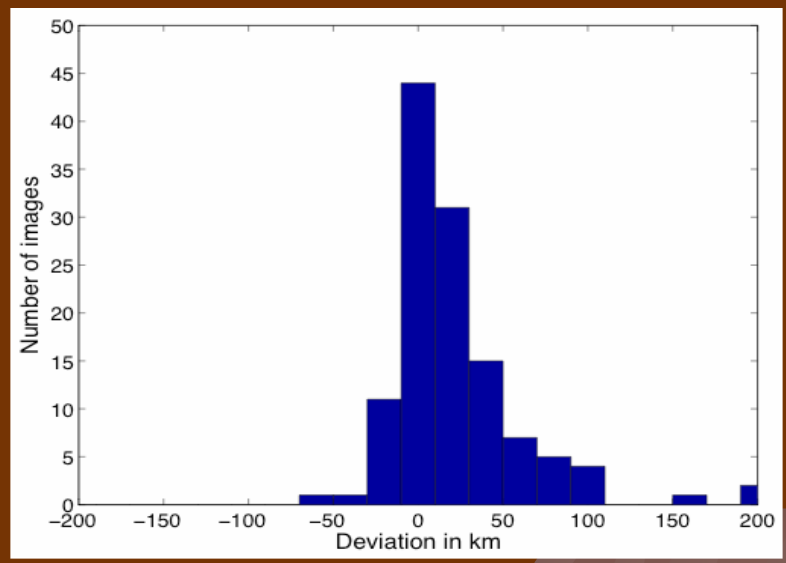
- Mean deviation in location of detected cap edge
  - For 80 images known to contain the cap edge
- Standards
  - TES year 3 model, error estimate: 1.4 degrees (+/- 84 km)
  - Manual annotations, error estimate: 0.17 degrees (+/- 10 km)
- Results
  - BIT vs. TES model: 1.2 degrees (72.6 km)
  - BIT vs. manual: 0.5 degrees (28.2 km)
  - Manual vs. TES model: 2.07 degrees (124 km)
    - Manual annotations have a strong southward bias

1.4 degree margin of error

BIT vs. TES model



BIT vs. manual annotations

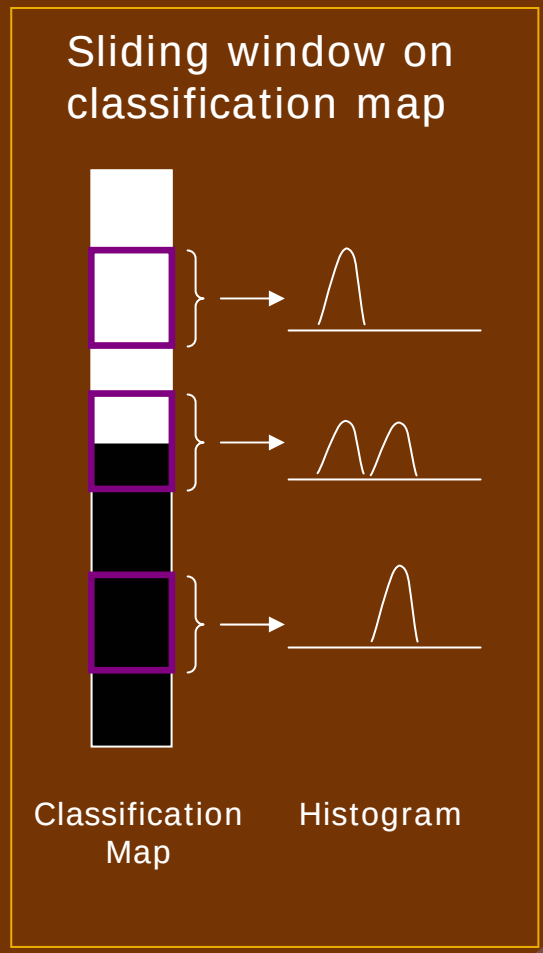


Seasonal Polar Frost Edge Operational Scenarios

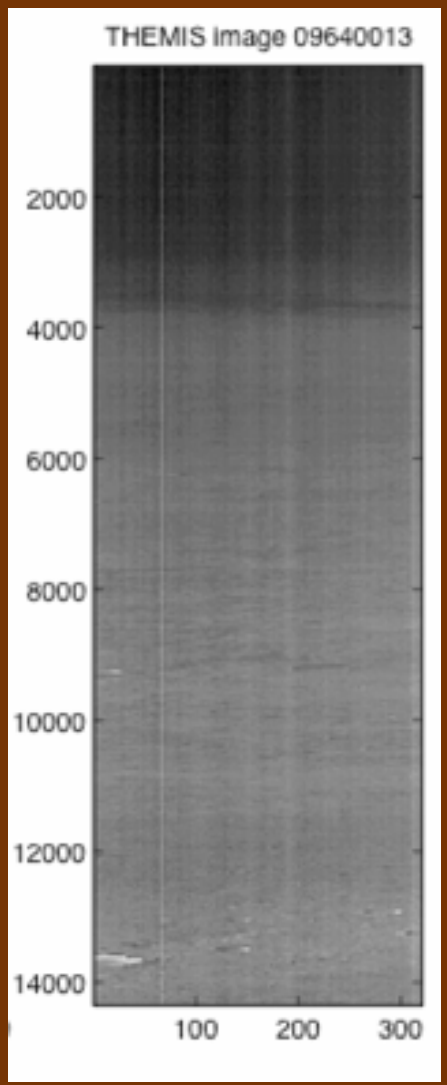
- Assumption
  - THEMIS operates in near-continuous data collection mode in polar regions
- Store and analyze a sliding window of image lines
- Options

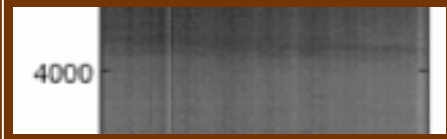
More bandwidth ↓

1. Downlink time-on-orbit of detection
2. Downlink image window with detection
3. Downlink a larger context image



Example Products



1. Time-on-orbit	2. Analysis window	3. Context image
Orbit 9640, spacecraft time 761370897.128	 Window = 1024 lines	 Context = 2048 lines
Bandwidth required:		
8 bytes	320 Kb	640 Kb

Window and context sizes are runtime parameters.

With 1024 lines, P(capture) = 71%.

With 2048 lines, P(capture) = 88%.

With 4096 lines, P(capture) = 98%.

With 12 orbits per sol, 71% or even less suffices.

Conclusions

- BIT is effective at detecting the CO2 cap edge
  - Evaluated on 435 THEMIS images
  - Good agreement with two independent standards
  - Agreement to within 28.2 km with manual annotations
- Designed for eventual onboard use
  - Does not require data calibration
  - Does require additional computation
  - Window size can be adjusted to suit available memory and desired processing speed
- Benefits
  - Greatly increase spatial and temporal coverage of cap recession
  - Can aid in data prioritization for downlink

Thank you to: Nghia Tang (JPL), the THEMIS science team, the New Millenium Program, and the Mars Odyssey Participating Scientist Program.